2 Physics Drivers

2.4 Strange and Charm Particle Production

High-statistics studies of exclusive strange-particle production by neutrinos will be possible for the first time in MINERνA. Sample sizes for several channels accessible to MINERνA in a four-year ν_μ run are summarized in Table 2.4.3. Cross section measurements afforded by these samples will impact other areas of particle physics, for example in estimation of atmospheric neutrino ΔS backgrounds to nucleon-decay searches. MINERνA's physics program will also include searches for new processes, *e.g.* strangeness-changing neutral-current reactions and unusual baryon resonances. Extended running of the NuMI beam with $\bar{\nu}$ exposures will provide valuable data for many neutrino topics. Anti-neutrino exposure will facilitate study of $\Delta S = 1$ single-hyperon production (Λ, Σ, Y^*), and would permit a novel measurement of CKM matrix elements. Selected topics and their motivations are summarized below.

2.4.1 Backgrounds to Nucleon Decay

Current lifetime limits for nucleon decay ($\tau/\beta \geq 10^{33}$ years) have not diminished hopes for the eventual success of supersymmetric grand unification (SUSY GUTs). Indeed, there is strong motivation to proceed with more ambitious experimental searches. For the near future, improved searches will be carried out by Super–Kamiokande. Eventually these will be taken up by a next generation of underground detectors. Continued progress, either by improving limits to 10^{34} year lifetimes or discovering nucleon decay, hinges upon improved knowledge of certain neutrino interactions which, when initiated by atmospheric neutrinos, can imitate nucleon-decay signals. The most problematic of background reactions to SUSY GUT modes arise with neutral-current associated production of strangeness at threshold energies.

2.4.2 Measurement of $\sigma(\nu \Lambda K^+)$

We propose to measure the exclusive $\Delta S = 0$ neutral-current channel

$$\frac{d\sigma}{dE_\nu}(\nu_\mu p \to \nu_\mu K^+ \Lambda), \tag{1}$$

from its threshold at ≈ 1 GeV through its rise and plateau at E_ν between 10-15 GeV. For purposes of comparison and as a valuable check on systematics[1], we will simultaneously measure the the $\Delta S = 0$ companion charged-current reaction

$$\frac{d\sigma}{dE_\nu}(\nu_\mu n \to \mu^- K^+ \Lambda). \tag{2}$$

2.4.3 Strangeness-changing Neutral Currents

Strangeness-changing neutral-current reactions have never been observed. Their occurrence at rates accessible in NuMI would imply new physics beyond the Standard Model. Existing limits on NC $\Delta S = 1$ processes are based upon searches for rare K decays. Although there are experimental difficulties with unambiguous identification of such processes in neutrino reactions, there is nevertheless an opportunity for a search in the neutrino sector. A search for strangeness-changing neutral-current neutrino interactions can usefully clarify the extent to which new physics parameters may be missing from the analysis

Reaction Type	Exclusive Channel	No. Events (≥ 0 constraint)
$\Delta S = 0$ CC	$\nu_\mu n \rightarrow \mu^- K^+ \Lambda^0$	23,100
	$\nu_\mu n \rightarrow \mu^- \pi^0 K^+ \Lambda^0$	20,400
	$\nu_\mu n \rightarrow \mu^- \pi^+ K^0 \Lambda^0$	13,800
	$\nu_\mu n \rightarrow \mu^- K^- K^+ p$	11,200
	$\nu_\mu p \rightarrow \mu^- K^0 K^+ \pi^0 p$	3,300
$\Delta S = 1$ CC	$\nu_\mu p \rightarrow \mu^- K^+ p$	34,900
	$\nu_\mu n \rightarrow \mu^- K^0 p$	5,200
	$\nu_\mu n \rightarrow \mu^- \pi^+ K^0$	4,600
$\Delta S = 0$ NC	$\nu_\mu p \rightarrow \nu K^+ \Lambda^0$	7,900
	$\nu_\mu n \rightarrow \nu K^0 \Lambda^0$	2,400
	$\nu_\mu n \rightarrow \nu K^0 \Lambda^0$	6,100

Table 1: Event samples for kinematically constrainable exclusive strangeness production reactions, in a four-year exposure of MINERνA's three-ton inner fiducial volume.

of weak radiative hyperon decays. It is plausible that neutrino reactions, in contrast to hyperon weak decays, may provide cleaner signals for a new weak current, since multi-loop quark-gluon diagrams which complicate hyperon decay analysis would be absent.

2.4.4 Hyperon Beta-decay and Exotic Quark States

Hyperon beta-decay $A \rightarrow B\, e^- \, \bar{\nu}_e$ provides a window onto weak hadronic current form-factors and their underlying structure. Recent high-statistics measurements of these form-factors using KTeV Ξ^0 hyperon beta-decays have been reported[2]; the results show that the level of SU(3) breaking is very small compared to expectations of modern theories[3]. These new results have been used to extract the CKM matrix elements V_{us}[4] [5]. Similar studies are possible using anti-neutrino interactions that produce hyperons. The hyperon decays have the added feature of a self-analyzing power of the polarization vector. In hyperon production via anti-neutrinos,the fundamental form-factors and CKM matrix elements will be accessible without the hindrance (encountered in hyperon beta-decay) of double solutions due to the missing neutrino energy.

Searches for $\Delta S = 1$ production of pentaquark states such as those recently reported[6], could be greatly extended in MINERνA. In neutrino-nucleus interactions wherein hyperons and mesons are produced together, a wealth of combinations can be examined to search for the full spectrum of the pentaquark family[7] of particles and for other exotic quark combinations such as di-baryons as well.

2.4.5 Charm Production

Charm production in MINERνA is suppressed by the relatively low energy of its beams, hence our reach will be limited. Nevertheless, the cross-section turn-on just above threshold is is very sensitive to the bare charm mass and MINERνA can still make a valuable contribution. With the proposed beam running schedule for MINERνA we expect $\sim 23,000$ of inclusive charm production events for a three-ton detector over the first four years, with an additional ~ 5000 charm events ($x_F > 0$) from subsequent anti-neutrino beam running.

References

[1] N.J. Baker *et al.*, Phys. Rev. D **24**, 2779 (1981).

[2] A. Alavi-Harati *et al.*, Phys. Rev. **87** 132001 (2 001).

[3] P.G. Ratcliffe, Phys. Rev. **D59**, 014038 (1999).

[4] N. Cabibbo *et al.*, Semileptonic Hyperon Decay and CKM U nitarity, [arXiv:hep-ph/0307214] (July 2003).

[5] T. Alexopoulos *et al*. (KTeV Collaboration), Phys. Rev. Lett. **93**, 181802 (2004).

[6] T. Nakano *et al.*, [arXiv:hep-ex/0301020]; V.V. Barmin
em et al., [arXiv:hep-ex0304040]; S. Stepanyan [arXiv:hep-ex/0307018].

[7] R. Jaffe and F. Wilczek, Di-quarks and Exotic Spectroscopy, [ar Xiv:hep-ph/0307341] (July 2003).